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Stereolithographic Modeling of Congenital Cardiovascular Malformations From Magnetic Resonance Images

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Background: Congenital cardiovascular (CV) malformations have many complex spatial characteristics that can be best appreciated by direct physical examination of the structures involved. Such assessment has heretofore been possible only at surgery and pathological examination. Recent advances in biomodeling have enabled automated production of plastic models from computerized three dimensional (3D) datasets. These methods are termed rapid prototype or stereolithographic modeling. **Purpose:** To determine the feasibility of production of stereolithographic models from tomographic magnetic resonance image (MRI) studies of patients with congenital CV disease. **Methods:** Patients were studied with standard MRI techniques, including turbo spin echo, segmented multiphasic gradient echo, and gadolinium contrast. After raw MRI data was acquired, computer assisted segmentation was performed on images of the anatomical structures of interest with a combination of thresholding and seeding. Sequential computer generated maximal intensity projections and surface rendered images were then generated. These surfaces were approximated via planes and straight lines, into tessellated facet format, the standard triangulation language (STL) interface. Physical anatomical models were then built from photosensitive plastic polymer using a stereolithography apparatus. **Results:** Physical replicas (n=15) were manufactured from images of CV structures of patients with a variety of malformations, including tetralogy of Fallot, transposition of the great arteries, preoperative and postoperative coarctation of the aorta, double aortic arch, total anomalous pulmonary venous connection, right aortic arch with aberrant left subclavian artery, pulmonary atresia with ventricular septal defect, and aortic atresia. Excellent correlation was present between measurements made on the models and measurements made from the original images. **Conclusion:** 1. Anatomically accurate plastic physical replicas can readily be produced from the MRI studies of congenital CV anomalies. 2. These replicas have potential to assist in the diagnosis and management of these complex disorders.

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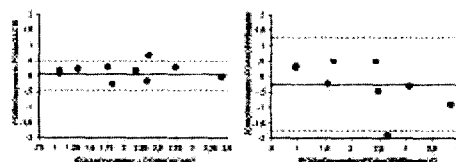
Automated Cardiac Output Measurement for Quantification of Intracardiac Shunt

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Background: Echocardiography is a reliable tool for the diagnosis of intracardiac shunt (ICS). However, the gold standard of ICS quantification remains catheterization. A new automated echocardiographic technique for the measurement of cardiac output measurement (ACM) has been recently developed. The aim of our study was to assess the feasibility and the accuracy of ACM method for quantifying ICS.

Methods: We studied 12 consecutive patients (10 men, mean age 43 ± 18 yrs) presenting atrial septal defect (n = 5) or ventricular septal defect (n = 7). All patients underwent blinded catheterization and echocardiographic quantifications of ICS. Each pulmonary and aortic cardiac output (PO and AoO) was assessed using following methods. 1) Fick output principle with invasive oximetric method, 2) pulsed-wave (PW) Doppler measurements, 3) ACM with double integration of Doppler signals in space and in time.

Results: Mean values (\pm SD) using catheterization, PW Doppler and ACM methods were respectively 9.8 ± 4.3 , 11.7 ± 9.2 and 9.7 ± 5.6 l/min for PO and respectively 4.8 ± 1.3 , 5.8 ± 3 and 5 ± 1.6 l/min for AoO. Correlations of PO/AoO ratio between catheterisation using oximetric method and echocardiography were 0.79 (for PW Doppler) and 0.94 (for ACM). Using ACM, Bland-Altman analysis revealed a very good agreement with invasive data (Figure). **Conclusion:** These data suggest that automated cardiac output measurement is a feasible and accurate method for quantifying intracardiac shunt in our population.



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Lesion Specific Pressure Recovery Phenomenon in Pediatric Patients: A Simultaneous Doppler and Catheter Correlative Study

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Background: Pressure recovery (PR) phenomenon mainly accounts for the discrepancy between Doppler predicted and catheter measured pressure gradients (PG) across stenotic lesions. PR depends on the geometry of the lesion and the receiving chamber in vitro studies. We prospectively studied the PR magnitude and its effect on Doppler-catheter gradient relation in different stenotic lesions in pediatric patients.

Methods: Simultaneous double blind Doppler and catheter PGs were prospectively measured pre- and post-intervention in 91 consecutive patients (age: median 12.2 mo., range 1-224 mo.; wt: median 7.5 kg, range 2.8-72kg) with isolated coarctation of aorta (n=36), aortic (n=30), and pulmonary (n=25) stenoses. PR (aortic stenosis) was derived by $4V^2 \times 2AVA/AOA \times (1-AVA/AOA)$, where Doppler peak velocity (V), aortic valve area (AVA) by continuity equation, and ascending aortic cross-section area (AOA) from its diameter were calculated. PR for pulmonary stenosis and coarctation were similarly derived.

Results: Predicted recovered pressures compared well with observed Doppler-catheter PG discrepancies ($r = 0.93-0.95$), which were the highest for coarctation for all range of peak-to-peak gradients (Table) and for lesion area/receiving chamber area approaching 50%.

Peak-to-Peak	% Overestimation by Doppler PG due to PR		
Cath PG (mmHg)	Coarctation	Aortic Stenosis	Pulmonary Stenosis
25-49	$32 \pm 6^*$	23 ± 3	21 ± 4
50-74	$52 \pm 3^*$	41 ± 4	38 ± 5
>75	$43 \pm 2^*$	21 ± 7	24 ± 2

* p-value < 0.05 when compared to aortic & pulmonary stenoses

Conclusion: Doppler PG may overestimate catheter PG up to 50% due to PR which occurs more in discrete coarctation than in isolated valve stenoses and as lesion area/receiving chamber area approaches 50%.

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Myocardial Strain Rate Is Superior to Tissue Doppler Imaging for Evaluation of Left Ventricular Subendocardial Function

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Background: The purpose of this study was to evaluate the subendocardial wall function using strain rate imaging. **Methods:** We studied 8 open-chest sheep using tissue Doppler imaging (VingMed Vivid FiVe) in apical 4-chamber views, to examine both septal and free walls. Peak strain rate which can be observed during isovolumic relaxation (IR) and negative peak strain during isovolumic contraction (IC) were measured in endocardium (End), myocardium (Mid) and epicardium (Epi). After scanning the baseline condition, we changed hemodynamic status by administering blood, dobutamine and metoprolol infusion. **Results:** There was a significant difference in strain rate between the myocardial layers for both isovolumic contraction and relaxation (End: 2.2 ± 1.5 ; Mid: 1.0 ± 0.8 ; Epi: 0.67 ± 0.64 during IR, End: -3.4 ± 2.2 ; Mid: -1.8 ± 1.5 ; Epi: 0.63 ± 1.0 during IC; $p < 0.05$). However, tissue Doppler measurements of the 3 layers showed that while velocity of End was higher than that of Epi, this difference was not significant. Also, strain rate of End during IC was significantly altered by hemodynamic condition (baseline: 1.7 ± 0.7 ; blood: 2.0 ± 1.1 ; dobutamine: 3.4 ± 2.3 ; metoprolol: 1.0 ± 0.4 ; $p < 0.05$). For Mid and Epi, however, there was no significant difference of IC strain values among the 4 hemodynamic conditions. Lastly, endocardial strain rate during IC showed a good correlation with positive dP/dt ($r=0.73$, $p<0.001$) recorded with high fidelity manometer tipped catheters.

